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Improving the working performance of automatic ball balancer by modifying its mechanism

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ABSTRACT

An automatic ball balancer consists of several balls that are free to move in the circular race containing a damping fluid. Although a traditional ABB can improve the vibration behavior of an unbalanced rotor under proper working conditions, at speeds below the first critical speed, it makes the vibration amplitude of the rotor larger than that of a rotor without an automatic ball balancer. Moreover, it has a limited stable region of the perfect balancing configuration. Considering these deficiencies, in this study a new design for automatic ball balancer is proposed. To analyze the problem, the nonlinear governing equations of a rotor equipped with the new ABB are derived using Lagrange's equations. Then, stability analysis is carried out on the basis of linearized equations of motion around the equilibrium positions to obtain the stable region of the system. It is shown that the new ABB can prevent the rotor from increasing the vibrations at the transient state. Also, it increases the stable region of the perfect balancing configuration. Comparing the results with those corresponding to the traditional ball balancer shows that the new ABB can reduce the vibration amplitude at speeds below the first critical speed and it increases the stable region of the perfect balancing configuration.

1. Introduction

Automatic ball balancers are used to reduce the vibrations of rotors with variable imbalance. If the rotor has a fixed amount of imbalance, it is easy to balance the system by adding or removing correction masses. However, if the mass distribution of the system changes according to the operating conditions, it is difficult to predict where and when the imbalance will occur, and the perfect balancing configuration of the rotor cannot be achieved by applying the balancing procedure only once and needs to be repeated. These observations motivate the study of automatic ball balancers. ABB devices are employed in industrial applications such as machine tools and optical disk drives [1–4]. An automatic ball balancer consists of several balls that are free to move in the race containing a damping fluid. Under proper working conditions, the balls settle at specific positions and counterbalance the imbalance of the rotor. These particular positions are referred to as the perfect balancing positions.

The first theoretical study of an ABB was carried out by Thearle [5]. Tadeusz [6] investigated the effects of rolling resistance of ball motion, eccentricity of the runway and the external vibrations on the rotor-balancer system at steady state. Chung and Ro [7] and Lu et al. [8] studied the dynamic behavior and stability of plane Jeffcott rotor with ABB. Lu et al. [9]

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Nomenclature

C	geometric center of the rotor	m_d	mass of the rotor
f	the ratio of the natural frequency of the ball-radial spring assembly to the natural frequency of the system	$\overline{m}$	non-dimensional ball mass
G	mass center of the rotor	β	auto-balancer damping ratio
J	mass moment of inertia of the rotor with respect to G	$\overline{\varepsilon}$	non-dimensional eccentricity
K_p	stiffness of the peripheral springs	ϕ_i	angular position of ith ball
K_r	stiffness of the radial springs	ω	angular velocity of the rotor
m_b	mass of a ball	ω_n	natural frequency of the rotor
		ω_b	natural frequency of the ball-radial spring assembly
		$\overline{\omega}$	non-dimensional rotational speed
		$\dot{\overline{\omega}}$	non-dimensional rotor acceleration
		ζ	the system damping ratio

investigated the stability of the perfect balancing positions of a three-ball ABB. Hwang and Chung [10] studied the dynamic behavior of the planar ABB system with balls running in double races. Green et al. [11] presented a nonlinear bifurcation analysis of the dynamics of a rotor equipped with an ABB for the first time. The modeling and dynamic analysis of non-planar rotor with an ABB are considered in Refs. [12–16]. Yang et al. [17] investigated the influence of friction on the performance of automatic ball balancer. Wouw et al. [18] studied the balancing performance of an ABB with dry friction. Rodrigues et al. [19,20] and Sperling et al. [21] presented an analysis of a two-plane automatic balancing device for rotating machinery that can compensate for both mass eccentricity and principal axis misalignment. Ehyaei et al. [22] investigated the dynamic response and the stability of an unbalanced flexible rotating shaft equipped with a number of n ABBs, where the imbalance masses are distributed in the length of the shaft. Chan et al. [23] explored the effects on ball positioning because of the nonlinear suspensions of a rotor equipped with ABB. Sung et al. [24] investigated the influence of external excitations on ball positioning in an automatic ball balancer installed on a rotor system. Bykov investigated the self-balancing of a statically unbalanced orthotropic elastic rotor equipped with ABB [25].

Reviewing the previous studies indicates that ABB has numerous advantages such as low cost, simple structure and its ability to balance the rotors with varying imbalance automatically at certain conditions [26]. However, the traditional automatic ball balancer has two major deficiencies: First, at transient state, the state in which the speed of the rotor reaches from zero to its first critical speed during the run up, the rotor vibration amplitude is larger than that of a rotor without an automatic ball balancer [27]. The reason for increasing the vibration at transient state is that, below the critical speed, the balls in the race tend to move toward a side near the rotor mass center. To overcome this deficiency, Kim and Na suggested a new type of ball balancer in which the ball positions in the race are controlled by placing springs between the balls. When the rotor is at rest, these springs distribute the balls in the race evenly and prevent the balls from converging to one side under a low converging force as the result of low centrifugal force acting on the balls below the critical speed [28]. The other deficiency is that it has a limited stable region of the perfect balancing configuration, so it can balance the system only with specific values of parameters. Lu and Wang [29] proposed a new type of auto-balancer that was designed to increase the stable region of the perfect balancing position by attaching the balls to the radial springs.

An ABB which is free from the two mentioned deficiencies is not presented up to now. In this study, in order to overcome the mentioned deficiencies and improve the balancing performance, a new design is provided for automatic ball balancer. It is shown that the new design of ABB reduces the vibration amplitude at the transient state and increases the region of the perfect balancing condition. These characteristics of the new ABB increase the life time of the system and make it possible for the new ABB to tolerate a wider range of the system parameters in which the perfect balancing configuration is achieved.

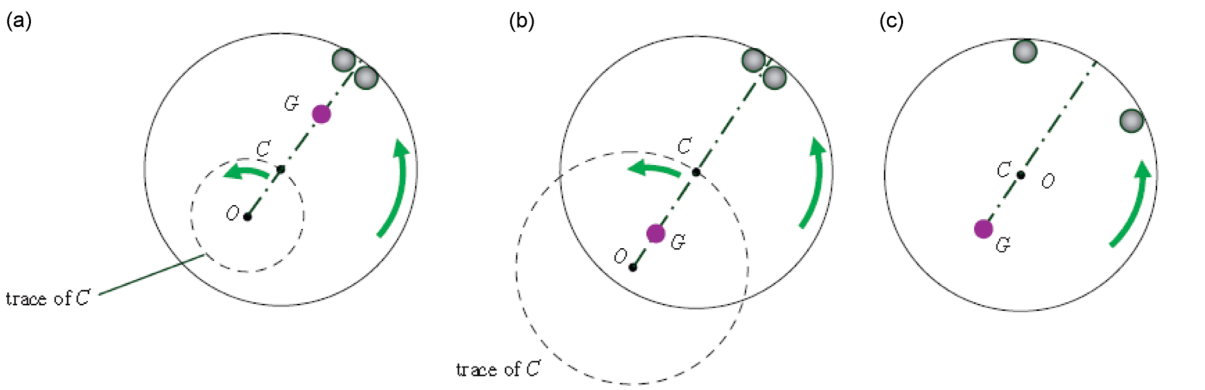

Fig. 1. Schematics of the configurations of the unbalance rotor equipped with ABB, (a) below the first critical speed, (b) above the critical speed and, (c) the perfect balancing condition [8].